Boosting Microwave Capacity Using Line-of-Sight MIMO

Introduction

Demand for network capacity continues to escalate as mobile subscribers get accustomed to using more data-rich and video-oriented services from their increasingly sophisticated devices. Deployments of 4th generation LTE/LTE-A mobile networks are poised to boost that demand even further as they promise to deliver subscribers a wireline experience in their wireless networks. In light of the significant increase in demand for network capacity, network operators are asking themselves whether cost-effective microwave can scale up to meet the ever-growing capacity demand.

The benefits of microwave as a transport technology are numerous and well known. Microwave is scalable. It is quick and inexpensive to deploy. It is highly reliable. It does not suffer from extended cessations in service such as experienced due to fiber cable breaks. It is the preferred transport medium provided that it scales to fiber capacity.

Line-of-Sight (LoS) MIMO (Multiple Input Multiple Output) is a new technology in microwave communications. Inspired by, but inherently different from the well-known non-line-of-sight MIMO technology widely used in access networks, LoS MIMO revolutionizes microwave communication in terms of capacity and spectral efficiency. In this paper, we discuss the technology, Ceragon’s implementation of LoS MIMO and its many benefits.

Microwave Technologies that Increase Capacity

There are numerous advanced microwave technologies that already enable operators to satisfy the growing demand for capacity. Co-channel dual polarization (CCDP) with XPIC technology, utilizing the different polarizations of a frequency channel, was the last advance that boosted spectral efficiency by an order of 100%. Since then, incremental improvements such as high modulation schemes (1024QAM, 2048QAM), packet compression, asymmetrical bandwidth delivery and Layer 1 link aggregation (Multi-Carrier Adaptive Bandwidth Control) techniques have been used to improve spectral efficiency and thus boost microwave capacity.

We are upon the next great leap in microwave technology that will improve spectral efficiency by another 100%: LoS MIMO. Originally a non-line-of-sight (NLoS) technology
that exploits signal multi-path caused by reflections from different physical obstacles, MIMO uses multiple transmitters and receivers to increase spectral efficiency by spatially multiplexing multiple bitstreams over the same frequency channel. NLoS MIMO is deployed mostly in access networks such as Wi-Fi, WiMAX and LTE where user equipment connects to the network.

In LoS microwave, the non-LoS multipath signal is weak and unusable for the purpose of MIMO. Instead, LoS MIMO achieves spatial multiplexing by creating an artificial multi-path not caused by physical objects, but rather by deliberate separation of antennas in such way that a deterministic and constant orthogonal multi-path is created.

![Figure 1 - NLoS MIMO (left) vs. LoS MIMO (right)](image)

**LoS MIMO Explained**

In order to understand the theory behind LoS MIMO, let us consider the link setup described in the following figure:

![Figure 2 - General LoS MIMO antenna setup](image)

A 2X2 MIMO microwave link comprises two transmitters and receivers connected to two antennas on each side. 4X4 MIMO is also achievable in this setup by using four transmitters and receivers in both H and V polarization. In order to keep things simple for
this example, we will consider only a single polarization (2X2). Spatial separation between antennas is denoted \( h_1, h_2 \) respectively, and the different signal path lengths are denoted \( d_{ij} \) for the length of the path between transmitter \( i \) and receiver \( j \).

Separation between signals is achieved by having them arrive at a specific and constant phase difference at the different antennas. Two different signals are transmitted on the same frequency and polarization, and therefore the “interfering” signals \( (d_{12} \) and \( d_{21} \) ) cannot be higher, and should rather be of equal power to that of the “desired” signals \( (d_{22} \) and \( d_{11} \) respectively). A signal processing algorithm is then applied to cancel cross-interference and to separate the signals. Control of the phase at which signals arrive is achieved through the length of the paths over which the signals traverse. The path length can be controlled by the distance of separation between antennas on each side of the link.

The following equation formulates the antenna separation distance required for optimal LoS MIMO operation:

\[
h_1 \cdot h_2 = \frac{D \cdot c}{2f}
\]

Equation 1

where \( h_1, h_2 \) denote the respective antenna separation distances on either side of the link (in meters), \( D \) denotes the overall link distance (in meters), \( c \) denotes the speed of light \( (3 \times 10^8 \text{ m sec}^{-1}) \) and \( f \) denotes the link frequency (in Hz).

Taking the symmetrical special case where antennas are equally and optimally separated on both sides, we achieve the optimal separation distance:

\[
h_{\text{optimal}} = \sqrt{\frac{D \cdot c}{2f}}
\]

Equation 2

Intuitively, we see that antenna separation does not have to be equal on both sides of the link. Constraints which may limit antenna separation on one side of the link (tower space, mechanical or wind load, etc.) can be compensated by adjusting antenna separation on the other side of the link so that the product of the antenna separation lengths satisfies Equation 1. The following diagram gives an idea of the symmetrical separation needed between antennas \( (h_{\text{optimal}}) \) for different link spans and in different frequencies:
Ceragon’s LoS MIMO Link Setup

A LoS MIMO link is set up by using Ceragon’s FibeAir IP-20C radio. FibeAir IP-20C is a multi-core\(^1\), all-outdoor packet radio with a single modem handling multiple bitstreams and allocating them between the two RF carriers integrated in each FibeAir IP-20C unit. In this way, a LoS 4X4 MIMO link can be set up by installing only two IP-20C units on each side of the link. Each unit is mounted directly onto an antenna (using an OMT\(^2\) mediation device), and the two units and the two units share & synchronize MIMO data. If a single stream of data is to be sent over the link, or if the customer wishes to protect the connection, then a networking device needs to perform some sort of link aggregation (splitting the data stream between the two FibeAir IP-20C units).

\(^1\) More information on multi-core technology can be found in a technical brief available on Ceragon’s [website](#).

\(^2\) Orthogonal Mode Transducer: A mediation device designed to combine two orthogonally polarized carriers in the same antenna port.
Ceragon’s LoS MIMO Link Robustness

One of the main considerations with LoS MIMO operation is the sensitivity of the link to the accuracy of the installation: how does inaccurate antenna separation affect the quality of the MIMO link? The following figure shows antenna separation sensitivity in Ceragon’s MIMO implementation:

Figure 5 - Continuum of optimal installation scenarios

Figure 5 shows how signal-to-noise ratio (SNR) or equivalently, mean square error (MSE), is affected by using sub-optimal antenna separation, relative to the optimal separation, $h_{\text{optimal}}$. In the case of optimal installation (point A), we achieve a 3dB MSE improvement compared to a 1+0 SISO link. It also demonstrates that the trade-off between antenna separation on both sides of the link yields a continuous line of optimal installation scenarios, and that sub-optimal antenna separation on one side can be offset by the separation on the opposite side.

So, for example, in cases where deviation in antenna separation is 10% on each side (point B), we can lose about 1dB in MSE compared to optimal installation, yielding only a 2dB MIMO gain (compared to a 1+0 SISO link).

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3 Single Input Single Output: Classic microwave installation with a single antenna on each side
A second example demonstrates that 20% deviation on each side (point C) will lead to a similar MSE as in the SISO reference (3dB decline cancelling the 3dB MIMO gain), but still enjoying most of the capacity gain of MIMO. From this, we see that Ceragon’s LoS MIMO implementation is quite immune to sub-optimal antenna installation, and perfect accuracy does not have to be established during installation in order to gain the capacity benefit.

Figure 6 further demonstrates how sub-optimal antenna separation affects the capacity (relative to an optimal installation).

Figure 6 - Effect of sub-optimal installation on capacity (max. capacity is at 1024QAM)
Antenna-Related Considerations

Another important consideration with LoS MIMO is the antennas themselves – their installation and their size. First, we must understand that antenna separation does not have to be a vertical separation. On masts and poles, it is convenient to separate the antennas vertically, but horizontal separation (e.g., in a rooftop installation) will also deliver the full effect of LoS MIMO as long as the axis of separation is consistent on both sides of the link.

![Figure 7 - Horizontal or vertical antenna separation](image)

MIMO links also need to show high immunity to mast/pole movements due to wind, mechanical vibrations, etc. For that, an experiment was conducted to test Ceragon’s MIMO resilience to mechanical vibrations:
As we can see in Figure 8 (top), the installation was subjected to mechanical duress of up to six g-forces\(^4\). In Figure 8 (bottom), we see that this had only marginal effect on the link’s MSE rates, with negligible fluctuations of 1%, maintaining a stable, error-free link even under extreme vibrations.

\(^4\) \(1g \approx 10 \frac{m}{s^2}\)
The effect of different antenna sizes on LoS MIMO link behavior also needs to be addressed. Tower space, mechanical or other constraints may force installation of different-sized antennas for the MIMO link. As previously mentioned, both the “desired” and the “interfering” signals should be received at similar power (RSL). This, in turn, means that link budgets of both “desired” and “interfering” signals should be matched. If the aforementioned installation constraints force installation of a smaller antenna on one side of the link (Figure 9-A), we can even out this link budget imbalance by either lowering Tx power on the paired MIMO transmitter (Figure 9-B), or by reducing the size of the paired MIMO antenna as well (Figure 9-C).

Figure 9 - Asymmetrical antenna installation in LoS MIMO links
Benefits of Using LoS MIMO

Microwave radios operating in LoS MIMO provide a fresh set of benefits including capacity boost, lower TCO, and higher immunity to noise and interference.

**Multiplying capacity**
LoS MIMO enables transmission of two independent bitstreams over the same frequency and same polarization. This means 100% more capacity in a 2X2 MIMO configuration compared to a 1+0 SISO link without wasting additional spectrum resources. Using both polarizations of a frequency channel, i.e., employing a 4X4 MIMO scheme, enables transmission of four independent bitstreams over the same frequency channel and an effective gain of **four times** more capacity than a standard 1+0 SISO link or two times more capacity than a 2+0 SISO XPIC link.

**Reduced spectrum licensing fees**
MIMO isn’t just about multiplying capacity; it’s also about multiplying spectral efficiency. With more data transmitted over less spectrum, operators can save up to 75% on frequency license-related OPEX.

**Immunity to dispersive fading**
Spatially separated antennas employed in MIMO can also provide the benefit of space-diversity link protection and result in higher immunity to dispersive fading than SISO links.

**Improved system gain**
Combining received signals from both antennas boosts system gain by 3dB (as noise is uncorrelated between receivers), similar to that achieved by space-diversity systems with IF-combining. Further improvement to system gain can be achieved at the expense of the capacity boost by splitting a bitstream between transmitters operating in MIMO, thus enabling reduction of modulation scheme and, in turn, increasing system gain (both Tx power and Rx sensitivity). This can help in achieving longer link distances, reduced antenna sizes, or spectrum decongestion by utilizing higher frequencies for long-distance links. An improvement of as much as 20dB can be achieved.
Summary

MIMO has been widely used in access technologies as a means of increasing spectral efficiency through exploiting NLoS multipath in order to spatially multiplex multiple signals over the same frequency channel. Advanced microwave uses this technology in a LoS setup by installing multiple antennas with a calculated separation between them. This method boosts microwave spectral efficiency and throughput by 100% allowing microwave transport to scale with the escalating demand for capacity by mobile network users and achieving 2Gbps of uncompressed radio throughput per channel, thus matching fiber capacity.

With Ceragon’s LoS MIMO, network operators can enjoy all the benefits of microwave while adding significant capacity to their networks, and for very little cost. Ceragon’s LoS MIMO implementation is field-proven and unique in its robustness and ability to perform well even under extreme conditions such as sub-optimal antenna separation and harsh antenna movement.

LoS MIMO indeed revolutionizes microwave communication in terms of capacity and spectral efficiency.

About Ceragon Networks Ltd.

Ceragon Networks Ltd. (NASDAQ: CRNT) is the #1 wireless backhaul specialist. We provide innovative, flexible and cost-effective wireless backhaul solutions that enable mobile operators and other wired/wireless service providers to deliver 2G/3G, 4G/LTE and other broadband services to their subscribers. Ceragon’s high-capacity, solutions use microwave technology to transfer voice and data traffic while maximizing bandwidth efficiency, to deliver more capacity over longer distances under any deployment scenario. Based on our extensive global experience, Ceragon delivers turnkey solutions that support service provider profitability at every stage of the network lifecycle enabling faster time to revenue, cost-effective operation and simple migration to all-IP networks. As the demand for data pushes the need for ever-increasing capacity, Ceragon is committed to serve the market with unmatched technology and innovation, ensuring effective solutions for the evolving needs of the marketplace. Our solutions are deployed by more than 430 service providers in over 130 countries.

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